Improving and Developing Predictive Backscatter Models of Fish

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LONG-TERM GOALS

The long-term goal of this program is to quantify, understand, and visualize how the biology of aquatic organisms interacts with the physics of sound to produce acoustic backscatter data. Research activities integrate backscatter model predictions with laboratory and field measurements and combines results in computer visualizations and animations. Understanding scattering processes enables accurate population abundance estimates and contributes to acoustic species identification.

OBJECTIVES

Objectives of this research include incorporating digital image format in backscatter modeling input from a common database structure, examining performance of aggregation detection algorithms, and quantifying the effects of yaw on backscatter intensities.

APPROACH

Backscatter models, predominantly the Kirchhoff-ray mode (KRM) model, are used as investigative tools to examine how the biology of fish interacts with the physics of sound to produce acoustic data. Backscatter predictions for individual or groups of fish are compared to *ex situ* and *in situ* empirical measurements, and then used in computer visualizations to integrate results.

WORK COMPLETED

Three papers and a book review have been submitted for publication so far this year with an additional two manuscripts and a book chapter nearing completion. Seven presentations were made individually or in collaboration with colleagues at national or international meetings. Three visiting scholars, two students and an associate professor, received training and collaborated on research projects at the Fisheries Acoustics Research laboratory at the University of Washington.

Research efforts were directed at updating backscatter modeling computer programs, testing sensitivity of aggregation detection algorithms, and determining the influence of fish direction and position in beam on predicted backscatter intensity. Backscatter modeling data storage, program code, and data viewing have been reorganized and coordinated with those used by Mike Jech at the Northeast Fisheries Science Center. Activities included reorganizing batch mode in backscatter estimation programs; finalizing HDF5 data dictionary and integrating file transfer in KRM backscatter programs; and extended an application to import DIACOM format image files in a file viewer and added ability

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to detect multiple backscattering structures within fish bodies. We now have an updated and integrated suite of backscatter modeling and associated data storage and visualization programs.

Results of two research projects conducted in association with graduate students will also be highlighted in this report. In the first, a global sensitivity analysis was conducted on the algorithm implemented in the Echoview® software to detect and describe aggregations in acoustic backscatter. Multiple aggregation detections were performed using walleye pollock (*Theragra chalcogramma*) data from the eastern Bering Sea. In each aggregation detection, input parameters defining minimum size, density, and distance to other aggregations were selected at random using a Latin hypercube sampling design. Sensitivity was quantified by testing for correlation among input parameters and a series of aggregation descriptors. The second project examined how the direction of fish travel (i.e. yaw angle) and position in the acoustic beam interact to influence the amount of sound reflected by a fish. *In situ* target tracking data were combined with backscatter model predictions to estimate the influence of yaw and distance-off-axis on Pacific hake (*Merluccius productus*) target strength.

RESULTS

The CT Scan viewer organizes and visualizes stacks of DIACOM format files (Fig. 1). Controls in the left column enable cropping, rotating, zooming, and changes in display intensity of the image.

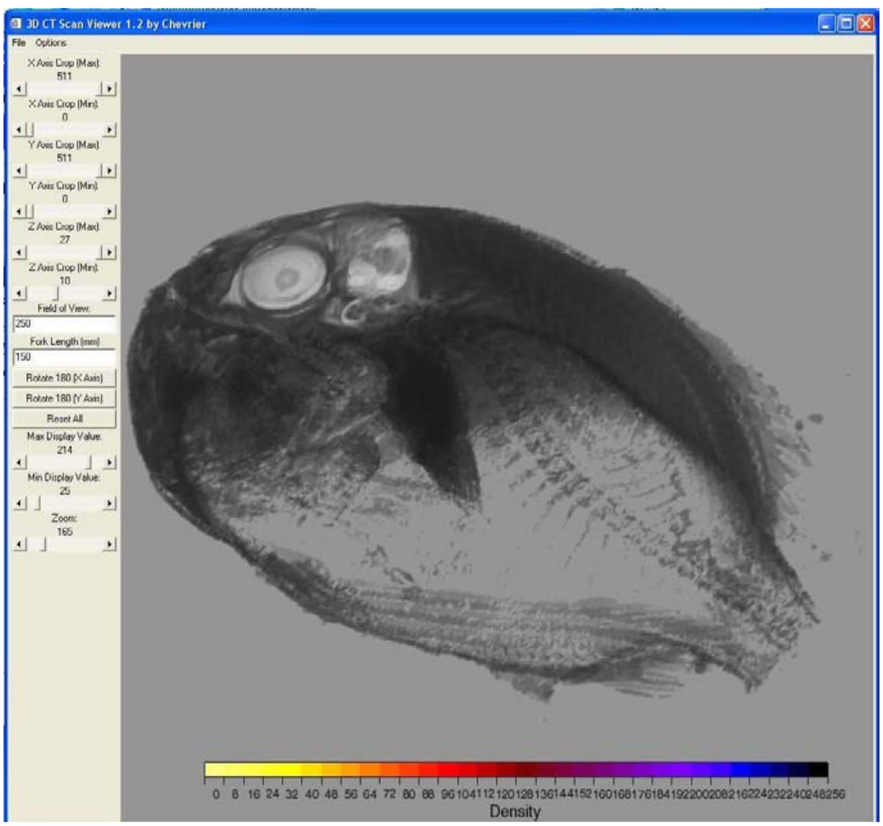

Figure 1. Screen shot of the CT Scan viewer showing an Magnetic Resonance Image (MRI) of an Orange roughy (Hoplostethus atlanticus). Slider bars on the left panel allow the user to adjust view characteristics and to adjust density thresholds.

Julian Burgos, a Ph.D student, chose walleye pollock as the test species for sensitivity analysis of aggregation detection algorithms because they form all aggregation types including midwater shoals, layers, and demersal aggregations (Fig. 2). Detected aggregations are sensitive to acoustic threshold, minimum aggregation size, and, to a lesser degree, the connectivity criterion. These results are applicable to similar aggregation detection algorithms and to other fish species that aggregate in large pelagic shoals, benthic layers, and discrete aggregations. Changes in the detection input parameters influence characteristics of detected aggregations, given that the detection process delimits regions of the echogram that satisfy acoustic density, size, and connectivity constraints defined by input parameter values. The goal of this effort is to establish a categorization of aggregation types.

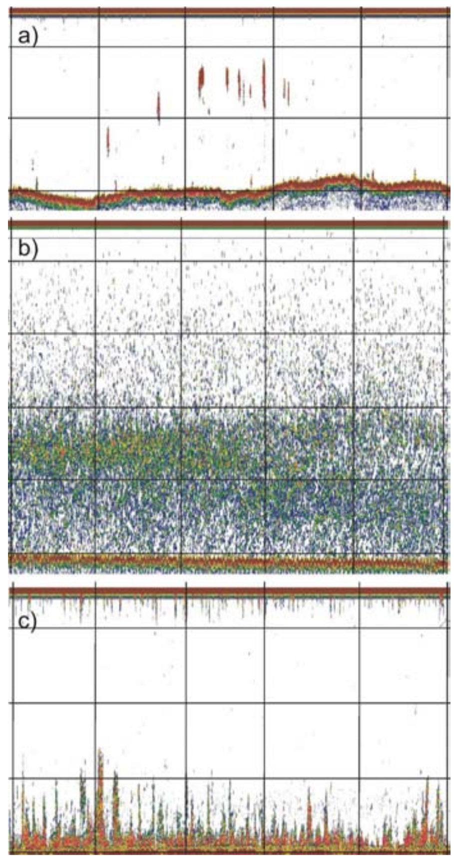

Figure 2. Representative walleye pollock (Theragra chalcogramma) 38 kHz echograms showing aggregation types including a) midwater shoals, b) layers, and c) demersal aggregations. Vertical divisions are 20 m and horizontal distances are half nautical mile segments

For his Master's research project, Mark Henderson examined the influence of orientation on the target strength of Pacific hake (*Merluccius productus*). The orientation of a fish relative to the transducer, in combination with the fish's position in the acoustic beam, influences the amount of sound reflected from a fish. If a fish is directly abeam and traveling parallel to the vessel's heading, then the incident acoustic beam will strike the side of the fish. In contrast, the incident acoustic beam will strike a fish on the head or tail if that fish is abeam of the vessel and swimming perpendicular to the vessel heading. Using KRM backscattering predictions, the target strength was observed to change depending on acoustic frequency, distance from the acoustic axis, tilt angle, and direction of travel (Figure 3). The largest target strength differences were found when a fish was oriented perpendicular to the vessel (yaw= 90º or 270º). When a fish is oriented in the same direction as the vessel (yaw = 0º) or facing the opposite direction of the vessel (yaw = 180º). A fish directly on the acoustic axis always has the same target strength regardless of yaw. The interaction of yaw and beam position increased target strength a maximum of 5 dB at 38 kHz, and 19 dB at 120 kHz. At 38 kHz, an individual fish with tilt angles of –5º, 0º, and 5º had maximum target strength differences of 7 dB, 11 dB, and 5 dB with changes in yaw and beam position (Figure 3 a-c). At the same tilt angles, a fish measured at 120 kHz had maximum target strength differences of 10 dB, 19 dB, and 5 dB with changes in yaw and beam position (Figure 3 d-e). The influence of yaw and beam position on the target strength of an individual fish is comparable to the influence of tilt.

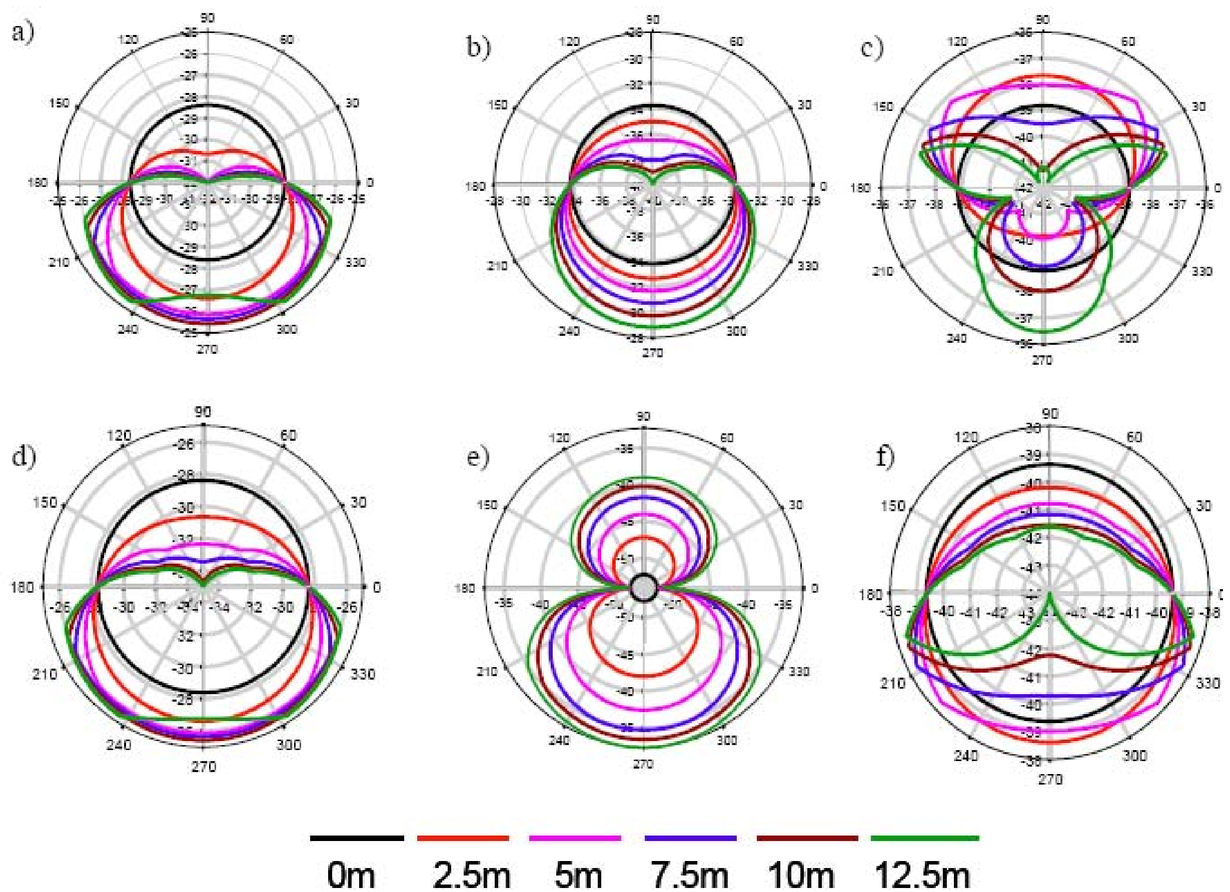

Figure 3. Polar plots of predicted influence of yaw and distance-off-axis for a 47 cm Pacific hake modeled at a) –5º tilt and 38 kHz, b) 0º tilt and 38 kHz, c) 5º tilt and 38 kHz, d) –5º tilt and 120 kHz, e) 0º tilt and 120 kHz, f) 5º tilt and 120 kHz.

When backscatter predictions are interpolated, contour plots illustrate the combined effects of yaw, tilt, and distance from acoustic axis. The effect is generally more pronounced at 120 kHz than at 38 kHz. Tilting the fish five degrees results in target strength differences as large as 14 dB at 38 kHz, and 26 dB at 120 kHz (Figure 4). Because the orientation of the swimbladder is different than that of the fish body, the influence of yaw and distance-off-axis on target strength is not symmetric at orientations of -5° (head down) and 5° (head up). Head up orientations have lower target strength values than fish with head down orientations, regardless of yaw. Although the combination yaw and distance-off-axis has a large effect on the target strength of an individual fish, these factors do not have a significant influence on the average target strength of an aggregation. An ANOVA found that there was no difference in average target strength whether an aggregation was swimming in a school (fixed yaw) or was shoaling (random yaw), regardless of fish's distance-off-axis.

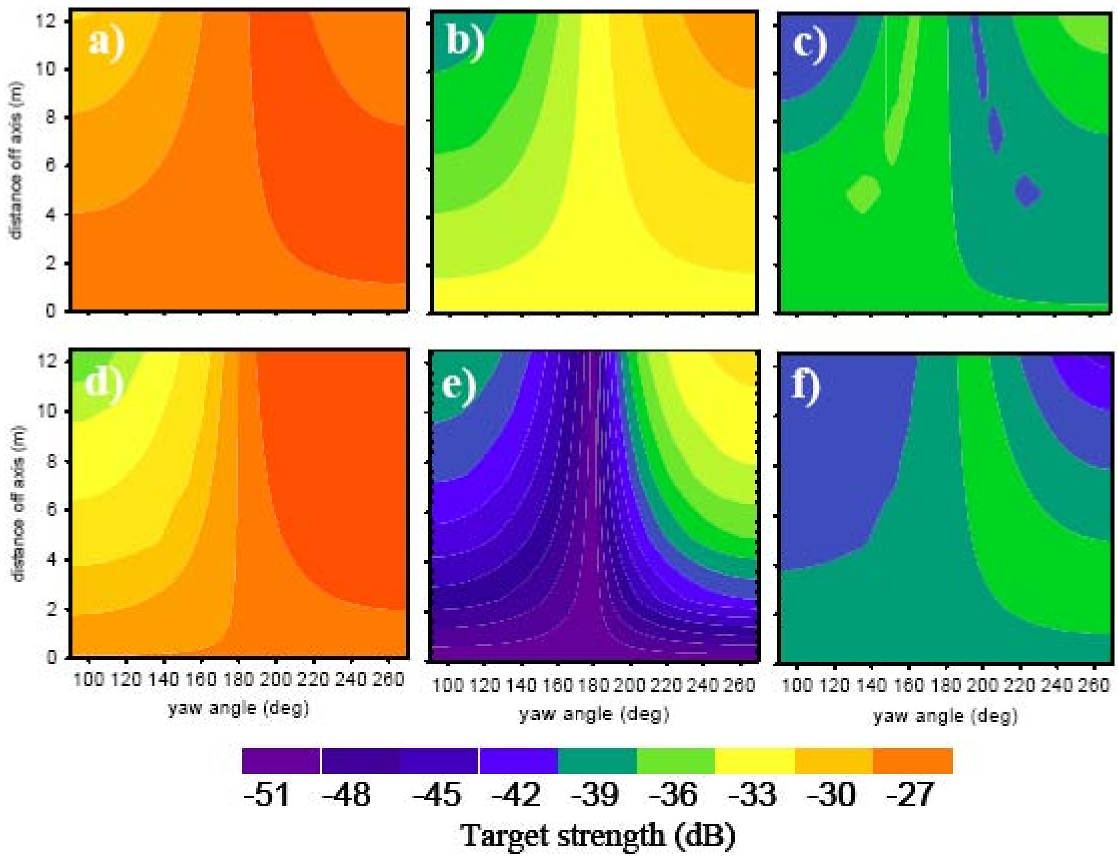

Figure 4. Contour plots of predicted influence of yaw and distance-off-axis for a 47 cm fish modeled at a) –5º tilt and 38 kHz, b) 0º tilt and 38 kHz, c) 5º tilt and 38 kHz, d) –5º tilt and 120 kHz, e) 0º tilt and 120 kHz, f) 5º tilt and 120 kHz.

IMPACT/APPLICATIONS

Continued coordination of data formats and computer programs ensures compatibility between east (Jech) and west (Horne) coast research laboratories and economizes on programming efforts. Expanded understanding of how fish act as acoustic targets increases the ability to interpret acoustic data and increases the accuracy of acoustic-based population estimates and species identification.

TRANSITIONS

Results from target strength modeling of Pacific hake in the northeast Pacific is been adopted by researchers at the Northwest Fisheries Science Center for population biomass estimates.

RELATED PROJECTS

Results from this project support efforts in the NOPP sponsored projects entitled, Development of Mid-Frequency Multibeam Sonar for Fisheries Applications (Horne, Jones) and Continuous Monitoring of Fish Population and Behavior by Instantaneous Continental-Shelf-Scale Imaging with Ocean-Waveguide Acoustics (Makris). Collaboration with Mike Jech has resulted in integration of backscatter modeling computer programs, fish morphological database formats, and data viewing capabilities.

PUBLICATIONS

Arnes, C., W. Melle, and J.K. Horne. Factors affecting feeding migration of planktivorous fish in an oceanic ecosystem. Marine Ecology Progress Series.

Burgos, J.M. and J.K. Horne. Sensitivity analysis and parameter selection for detecting aggregations in acoustic data. ICES Journal of Marine Science. (in press).

Burwen, D.L., P.A. Nealson, S.J. Fleischman, T.J. Mulligan, and J.K. Horne. Complexity of narrowband echo-envelopes as a function of fish orientation. ICES Journal of Marine Science.

Horne, J.K. "Fisheries Acoustics: Theory and Practice 2nd edition". E.J. Simmonds and D.N. MacLennan. Transactions of the American Fisheries Society. (in press).

PRESENTATIONS

Horne, J.K. Acoustic species identification: when biology collides with physics. 9th Western Pacific Acoustics Conference (WESPAC IX). Seoul, Korea.

Hwang, D.J., S. Kim, S. Jung, I. Choi, J. Horne, S. Parker Stetter, Y. Kim. Comparison of geostatistic and traditional acoustics estimates of anchovy biomass in Tongyoung fishing grounds. 9th Western Pacific Acoustics Conference (WESPAC IX). Seoul, Korea.

Horne, J.K. Acoustic species identification: when biology collides with physics. Medwin Prize invited lecture. 151^{tst} Meeting of the Acoustical Society of America. Providence, Rhode Island.

Horne, J.K., C.I.H. Anderson, and J. Boyle. Objective Classification of Multifrequency Backscatter. ICES Fisheries Acoustics Science and Technology Working Group annual meeting. Hobart, Australia.

Horne, J.K., K. Sawada, K. Abe, D. Barbee, and Y. Takao. Swimbladders Under Pressure: Anatomical and Acoustic Responses by Walleye Pollock. ICES Fisheries Acoustics Science and Technology Working Group annual meeting. Hobart, Australia.

Kaltenberg, A.M., K.J. Benoit-Bird, R.D. Brodeur, E.D. Brown, J.K. Horne, and J.H. Churnside. A Study of Sardines in the NE Pacific Using Multiple Platforms and Technologies. American Society of Limnology and Oceanography, Ocean Sciences Meeting. Honolulu, Hawaii.

Horne, J.K., J.H. Churnside, and P.M. Adam. Potential Integration of Acoustic and LIDAR Backscatter Data. American Society of Limnology and Oceanography, Ocean Sciences Meeting. Honolulu, Hawaii.

HONORS/AWARDS/PRIZES

Horne, J.K. Medwin Prize in Acoustical Oceanography. Acoustical Society of America.